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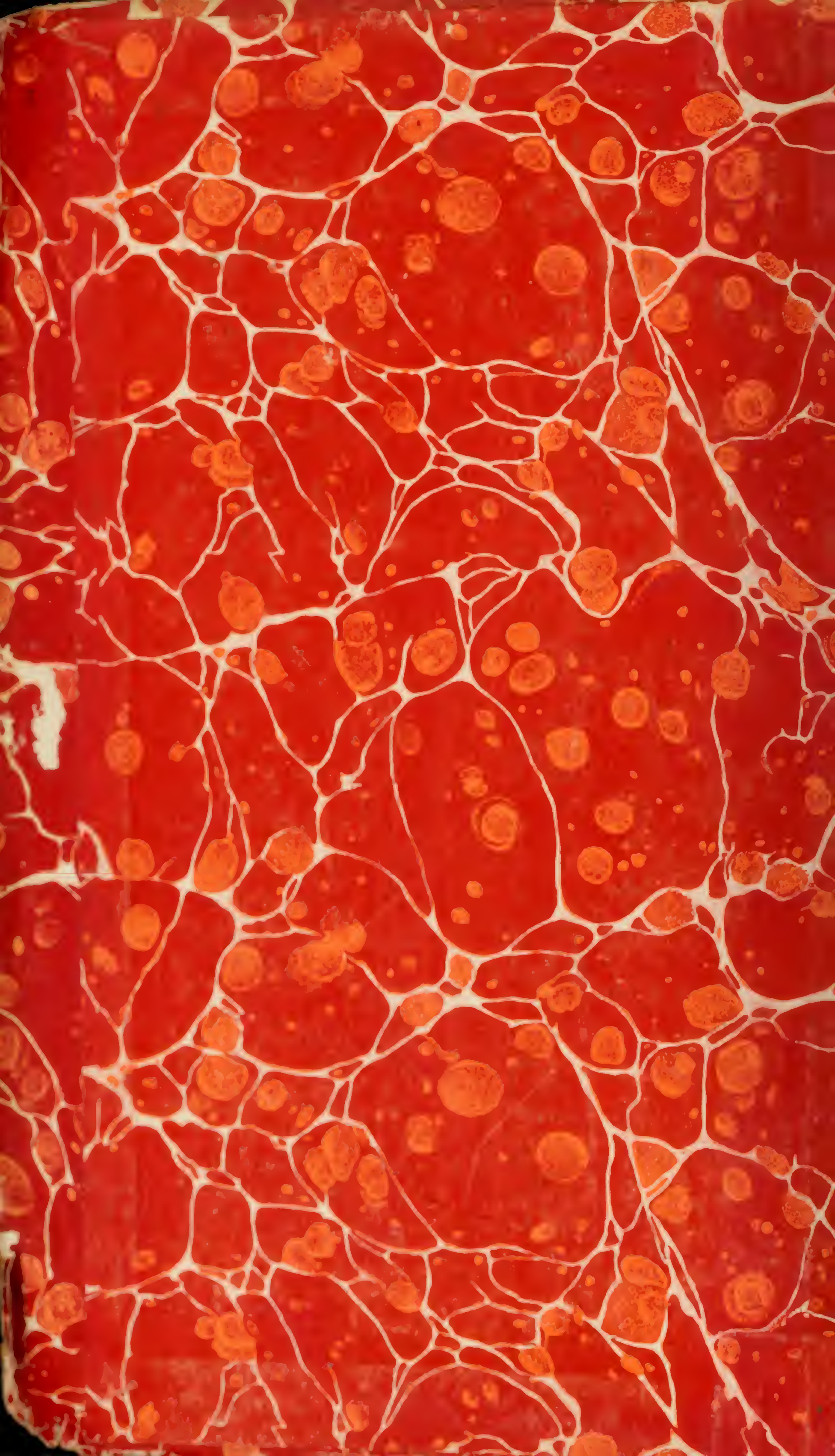

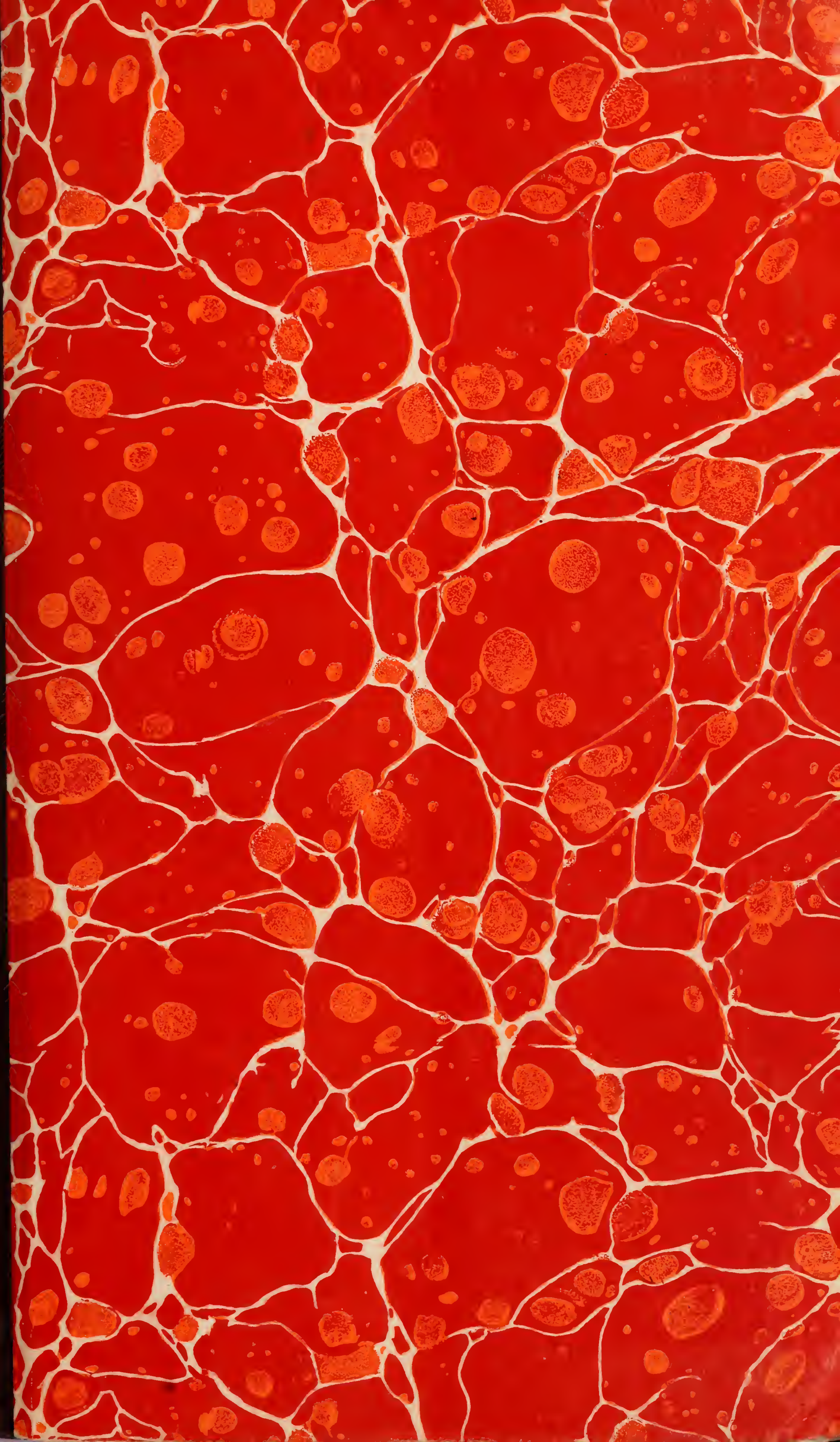

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DIMENSIONAL CHANGES IN THE MANUFACTURE OF ELECTROTYPES

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ABSTRACT

This investigation was conducted by cooperation between the International Association of Electrotypers and the National Bureau of Standards. Electrotypes made under typical but carefully controlled conditions were measured after each step in the process. The results showed that each operation is likely to produce some change in dimensions. The largest and most variable changes are produced in curving. By controlling all conditions it is possible to produce plates that will register with each other within about 0.05 per cent, though they will usually not have the same dimensions as the originals.

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I. INTRODUCTION

Electrotyping is extensively used for the reproduction of printing plates. In this process the details of the original, whether type or half tone, are faithfully reproduced. However, it has long been known that, unless special precautions are observed, the electrotypes are not exactly the same size as the originals. This difference, which in curved plates may be over 1 per cent, is usually not significant if the printing is done in one color, as then only one plate is involved.[3] In multicolor printing, however, two or more plates are employed; that is, one for each color used. For high-grade printing, these plates must have the same corresponding dimensions in order to register properly. Even in this case it is not essential that the different plates should be exactly the same size as the originals, but they must be alike in size. The difficulties sometimes encountered by commercial electrotypers in meeting this latter requirement led the International Association of Electrotypers to select this subject for study by their research associate at the National Bureau of Standards.

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[1] Research associate of the International Association of Electrotypers.

[2] Chemist, National Bureau of Standards.

[3] In printing certain charts, scale diagrams, or cross-section paper, accurate reproduction may be required even for 1-color plates.

This paper is a report of an investigation of this subject, in which the dimensional changes produced in each step of the electrotyping process were measured. In addition, the effects of changes in electrotyping conditions upon the changes in dimension were studied in order to determine how closely such conditions must be controlled to insure any given degree of uniformity in the size of the finished electrotypes.

II. OUTLINE OF THE ELECTROTYPING PROCESS

Electrotypes are made by depositing metal either upon wax molds or lead molds, of which the former are more extensively used. In wax molding, an impression of the original form is made by pressing the latter into a layer of wax that is attached to a flat metal plate. Graphite is then applied to render the wax surface electrically conducting, and metal is deposited on the graphite, forming a thin "shell." Sometimes the graphite surface is treated with a copper sulphate solution and iron filings, which produce a thin film of copper on the graphite. This process, known as "oxidizing," causes the metal to subsequently deposit almost at once over the entire surface, instead of "growing" over from the point where metallic contact is made with the graphite. In copper electrotypes, the shell consists entirely of copper, while in nickel electrotypes the first layer is nickel and the rest of the shell is copper. The nickel is used especially for large editions and for high-grade printing. At present chromium is often applied to finished nickel or copper electrotypes to increase their wear resistance.

A lead mold is made by pressing the original form into a thin sheet of lead. The lead mold is cleaned and treated with a chromate solution to permit separation of the subsequently deposited shell, which is generally of nickel and copper. Lead molds are used especially for half tones. Type-metal forms are not usually reproduced by lead molding, as the high pressure used is likely to deform the type. It is a general practice, however, to make lead molds from specially prepared electrotype patterns of a type subject.

The back of the shell is treated with a solution of zinc chloride which serves as a flux; after which "tin foil," consisting of about 35 per cent tin and 65 per cent lead, is laid on the surface. The shell is then placed face down on a flat cast-iron pan which is heated, usually by floating it upon molten lead or electrotype metal. When the tin foil has melted, molten electrotype metal is poured over the shell to the desired thickness. After the resultant plate is cool it is cleaned, trimmed, shaved on the back to approximately the desired thickness, "finished" to produce a plane printing surface, shaved to the exact thickness, and for flat presses is beveled or mounted on wood. If the plate is to be used on a rotary press, it is curved to fit the cylinder of that press. Any large nonprinting areas on the plate are usually "routed out," in order to prevent them from taking up ink and yielding it to the paper.

III. OUTLINE OF THIS INVESTIGATION

General observations indicated that each of the major steps in the above process might affect the dimensions, namely, the molding, depositing, casting, finishing, and curving. In a preliminary study, plates were made under typical commercial conditions, and the dimensions were measured before and after each of the above operations. These tests indicated the magnitudes of the changes produced in each step. The process was then carried out under more carefully controlled conditions, each of which was varied over definite limits, to determine the corresponding variations in the dimensional changes.

This investigation was facilitated by the active cooperation of the Potomac Electrotype Co., of Washington, D. C., and the Government Printing Office. In general, the molds were made in one of these plants, the shells were deposited at the National Bureau of Standards (in order to measure and control the current used on each plate), and the casting, finishing, and curving were done in the plants. The data, therefore, represent closely the results of actual electrotyping conditions.

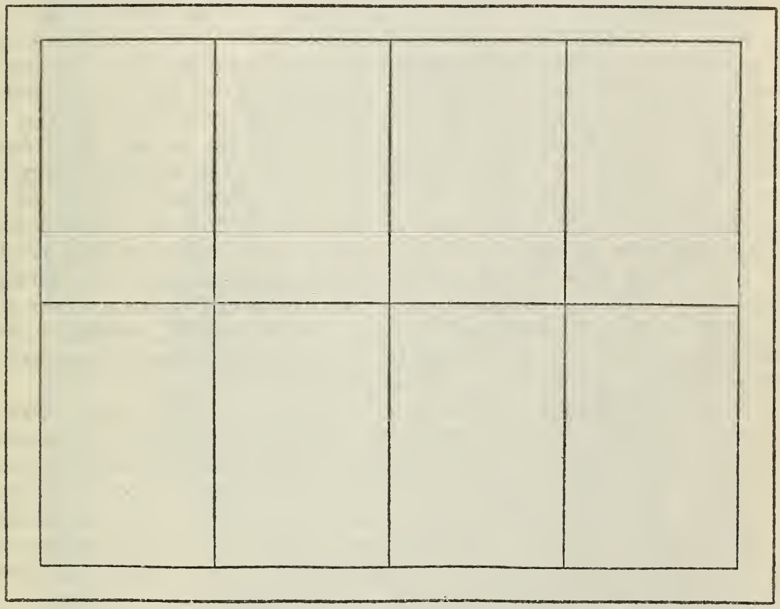

Figure 1.—*Design of "plain" pattern plate, showing lines used as gage marks*

The plate was 11 by 14 inches (28 by 26 cm).

In this study two pattern plates were used. The first, designated as the "plain" form, consisted of a polished copper plate about 11 by 14 inches (28 by 36 cm). Upon one side were ruled [4] fine lines, about 0.001 inch (or 0.025 mm) in width which formed a large rectangle divided into eight small ones, as shown in Figure 1. These lines served as gage marks, between which the distances were measured after each step in the process.

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[4] Through the courtesy of the United States Coast and Geodetic Survey.

The other pattern, designated as the "type" form, was an electrotype plate, the surface of which consisted mostly of type, with some "rules." This plate was about 9 by 12 inches (23 by 30 cm). Measurements were made between certain well-defined points on this plate and its reproductions.

These two patterns were selected to represent the extremes likely to be encountered in printing plates. Halftone plates are in very low relief, and hence approach the plain form. Commercial plates that include both type and halftone may reasonably be expected to yield results that are intermediate between those obtained with the two patterns used in this investigation.

No difficulty was experienced in measuring the distances between given points on flat plates by means of a graduated steel scale. It is however more difficult to measure accurately the distance between two points on a cylinder, especially if between these points a part of the cylindrical surface has been removed by "routing." If a flexible steel tape were used, it would tend to span the depression as a chord, instead of as an arc of the specified radius, and would hence not yield the true distance on the cylindrical surface, which latter is the actual printing surface. This difficulty was overcome by using the special gage shown in Figure 2, which was designed by one of the authors (W. B.). This gage was made from a polished flat steel plate about 15 by 8 by $\frac{3}{16}$ inches (38 by 20 by 0.5 cm). The arc had a radius of 6.250 ± 0.002 inch (158.8 ± 0.05 mm). This arc and one straight edge were graduated in linear units, the smallest division being 0.01 inch (equal to 0.25 mm). With an optician's lens, readings could readily be made to ±0.002 inch (0.05 mm). The gage was used for measuring both the flat and curved plates.

This particular gage was designed for the curved plates used in this investigation, which were made to fit the cylinder of a 3-color Sterling press. In order to make similar measurements on plates curved for different size cylinders, a separate gage would be required for each radius of curvature of the printing surface, which is one-half the so-called "bearer diameter." In a large electrotyping plant, this might necessitate the use of a large number of such gages if the dimensions of the curved plates were to be measured.

The dimensional changes are expressed in terms of (*a*) changes produced by a given step in the process, and (*b*) the net change from the original, produced by all operations performed up to and including that step. The latter values, or more strictly the final dimensions, are significant in the use of the plates; while the former show how variations in the latter may arise.

The register of two or more printing plates depends upon the actual differences in distance between corresponding points on the plates. Experience indicates that for fine printing; for example, of color process half tones, the extreme difference of corresponding points in the final impressions should be not more than about 0.003 inch (0.08 mm). To secure this accuracy of register, it is necessary that the dimensions of the plates should correspond only within about 0.005 inch (0.13 mm); as the effort is always made to have the plates register exactly at their centers, which causes half of the error to appear on each end. For practical purposes we may then consider that the object of this investigation was to define conditions that would insure an equality of length within ±0.005 inch (0.13 mm).

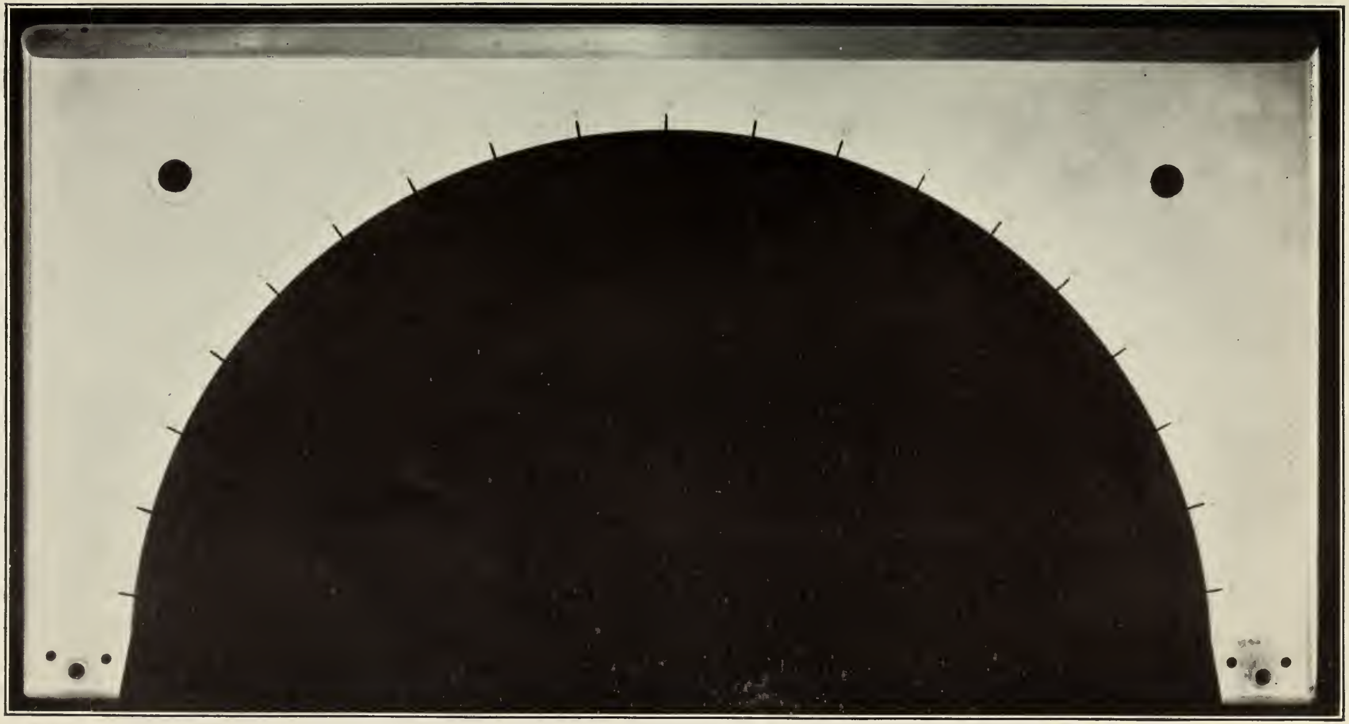

Figure 2.—*Gage used for measuring dimensions of curved electrotypes*

Both the arc and the straightedge were graduated in intervals of 0.01 inch.

Such a variation in length would, however, represent entirely different percentage discrepancies, according to the dimensions of the particular plate; for example, 0.1 per cent on a 5-inch (12.7 cm) plate, or 0.02 per cent on a 25-inch (63.5 cm) plate. Evidently, therefore, a measurement of the percentage variation is not in itself a criterion of the accuracy of register. As printing plates, including those made in this study, vary in dimensions, the only practicable way to express general conclusions is in terms of percentage changes. For any given size of plate the corresponding actual differences may then be calculated. Thus for a 10-inch (25 cm) plate, which is probably about the average length used commercially, each one-hundredth of 1 per cent is equal to 0.001 inch (or 0.025 mm). The general conclusions of this paper are based on a plate of about that length.

All the measurements reported in this paper were the averages of at least two plates, and in some cases of 10 or more. Except in a few cases that will be mentioned, the individual results were concordant to within about ±0.03 per cent. The changes were generally about equal in both directions, except in curving, when the significant changes occur only in the direction of curvature. In lead molding, changes in the two directions may be slightly different if the lead overlaps the pattern in one direction and not in the other. In the measurements here recorded, the lead projected beyond the pattern on all four sides, which is the common commercial practice. A positive sign attached to a change, for example, +0.03 per cent, indicates an increase in length ("stretch") and a negative sign a decrease ("shrinkage"). All measurements were made at room temperature, which was approximately 75° F. (24° C.).

IV. RESULTS OF EXPERIMENTS

The conditions used in each operation and the dimensional changes thereby produced, may conveniently be considered under each of the principal steps involved.

1. MOLDING

(a) WAX MOLDING

The cases used for wax molding were prepared by pouring molten wax consisting largely of ozokerite, to a depth of about 0.15 inch (4 mm) on a flat plate made of electrotype metal (containing about 93 per cent lead, 4 per cent antimony, and 3 per cent tin). The surface of the wax was shaved to make it plane, and brushed lightly with molding graphite to prevent the form from sticking. Molding was done in a hydraulic press at the slightly elevated temperature that is commonly used, and also at room temperature. The results in Table 1 show that in neither case was there any measurable difference in the dimensions of the original form and the wax mold.

TABLE 1.—*Dimensional changes in molding*

Experiment No.	Pattern	Mold	Molding temperature		Per cent change in molding
			°F.	°C.	
1	Plain	Wax	120	49	0.00
2	do	do	75	24	.00
3	do	Lead	75	24	+.05
4	Type	do	75	24	+.05

This result is somewhat surprising in view of the fact that the molding wax has a much higher coefficient of expansion than that of copper. If the wax were free to expand and contract laterally the wax mold made at a high temperature would become smaller than the copper pattern when both were again at room temperature. The expansion coefficients of some of the materials used in electrotyping are shown in Table 2.

TABLE 2.—*Approximate linear coefficients of thermal expansion*

Material	Parts per million per degree C.
Aluminum	23
Antimony	11
Copper	(0 to 50° C.) 16 (0 to 300° C.) 18
Nickel	13
Lead	31
Tin	23
Electrotype metal (93 per cent Pb, 4 per cent Sn, 3 per cent Sb)	28
Zinc	30
Molding wax (ozokerite base)	250

The values in this table for the metals are derived from those values in the literature that represent approximately the temperature ranges involved in this investigation. Aluminum is included because it or its alloys are sometimes used in the case on which the wax is poured. Zinc is included because zinc plates often serve as patterns for electrotyping. No values were found for electrotype metal. The value found [5] for a type metal containing 85 per cent lead, 12 per cent antimony, and 3 per cent tin is 25 parts per million per degree centigrade. The available data indicate that the expansion coefficient of ordinary electrotype metal, which contains 93 per cent of lead, is intermediate between this value and that of pure lead, or about 28 parts per million per degree centigrade. The expansion coefficient of electrotypers' wax varies with its composition. The value given in the table is the approximate average of a few samples on which purely preliminary measurements were made in connection with this investigation.

If then the wax expanded freely when heated from about 75° to 120° F. (24° to 49° C.), its length would increase by about $25 \times 0.000250 = 0.00625$, or 0.63 per cent. The copper form would expand in this same temperature range, by about $25 \times 0.000016 = 0.000400$, or 0.04 per cent. Hence, we would expect that on cooling, the wax mold would contract more than the copper and at 75° F. (24° C.) would be smaller than the original copper by the difference in these two expansions (or contractions); that is, by 0.63 minus 0.04 per cent, or practically 0.6 per cent. As no such difference was observed, it is evident that the layer of wax that is attached to the metal base, in this case type metal, is not free to contract or expand laterally, and that it retains very closely the size of the underlying plate. If this is true, the only change that would be measured after molding would be that due to the difference in expansion of the copper pattern and the type metal case. This would be equal to about $25 \ (0.000028 -$

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[5] Geo. F. Taylor, Phys. Review, **26**, p. 841; 1925.

0.000016) = 25 (0.000012) = 0.000300, or 0.03 per cent. This difference, which would result in −0.03 per cent change, is just about at the limit of observation, especially on wax molds. If, however, the copper pattern is expanded slightly by pressure, even at the moderate pressure used in wax molding, this will tend to compensate for the tendency of the mold to contract. At least the results show clearly that expansion of the molding wax does not lead to an appreciable change in lateral dimensions, and that differences in the composition or expansivity of the wax are not likely to affect the dimensions of the mold.

(b) LEAD MOLDING

As lead molding is done at ordinary temperature, there is no opportunity for dimensional changes to be caused by differences in thermal expansivity. Nevertheless it was found, as shown in Table 1, that the lead molds are slightly larger than the originals. This difference is undoubtedly due to the fact that at the higher pressures used in lead molding, the pattern expands slightly. If this expansion is within the elastic limit of the pattern metal, in this case copper, the pattern returns to its original length when the pressure is removed, while the lead, which has a very low elastic limit, retains the slightly larger dimension.

That the pattern plates do expand slightly in lead molding, even in extreme cases to the extent of a permanent change, is indicated by the fact that the plain pattern was 0.02 per cent larger in both length and width after about 100 impressions had been made from it. The type pattern was about 0.07 per cent longer and 0.02 per cent wider after about 50 impressions had been made. The greater expansion in length of the type plate was probably due to the fact that the type lines ran across the plate. Hence, the lateral pressure perpendicular to these lines was greater than that parallel with them. These very small changes in the size of pattern plates as a result of repeated molding have been reported by electrotypers.

2. DEPOSITION

It is well known that all electrodeposited metals are in a state of strain and tend to contract during their deposition. This contraction is most marked with the harder metals, and with those, such as nickel, that absorb much hydrogen. For a given metal the tendency to contract is greatest at a low temperature and a high current density, and increases with the thickness of deposit.

These well-known principles are illustrated by the data shown in Table 3. In these experiments the copper was deposited from a solution containing 250 g/l (33 oz./gal.) of copper sulphate ($CuSO_4.5H_2O$), 75 g/l (10 avoir. oz./gal.) of sulphuric acid (H_2SO_4) and 1.0 g/l (0.13 oz./gal.) of phenol, added as phenolsulphonic acid. Preliminary observations showed that the use of phenol as an addition agent produced no measurable change in the dimensions of the shells. (As will be noted later, it may affect the changes that occur in curving.) The nickel was deposited from a solution containing 70 g/l (9 oz./gal.) of nickel sulphate ($NiSO_4.7H_2O$) and 5 g/l (0.7 oz./gal.) of ammonium chloride (NH_4Cl) at a pH of about 6.4 (with brom cresol purple, uncorrected for salt error).[6]

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[6] W. Blum and N. Bekkedahl, Trans. Am. Electrochem. Soc., 56, p. 291; 1929.

TABLE 3.—*Dimensional changes in deposition*

Experiment No.	Pattern	Mold	Temperature of deposition				Current density				Thickness of shell				Change—	
			Nickel		Copper		Nickel		Copper		Nickel		Copper		In deposition	From original
			°F.	°C.	°F.	°C.	*Amp./ft.*^{2}	*Amp./dm*^{2}	*Amp./ft.*^{2}	*Amp./dm*^{2}	*Inch*	*mm*	*Inch*	*mm*	*Per cent*	*Per cent*
5	Plain	Wax	----	----	70	20	------	------	75	8	-----	-----	0.006	0.15	−0.07	−0.07
6	do	do	----	----	105	40	------	------	75	8	-----	-----	.006	.15	.00	.00
7	do	do	----	----	105	40	------	------	150	16	-----	-----	.006	.15	.00	.00
8	do	do	----	----	105	40	------	------	150	16	-----	-----	.012	.30	.00	.00
9	do	do	----	----	105	40	------	------	75	8	-----	-----	.012	.30	.00	.00
10	do	Lead	----	----	70	20	------	------	75	8	-----	-----	.006	.15	−.04	+.01
11	do	do	85	30	105	40	20	2	150	16	0.002	0.05	.012	.30	−.14	−.09
12	do	do	----	----	105	40	------	------	75	8	-----	-----	.006	.15	−.02	+.03
13	do	do	----	----	105	40	------	------	150	16	-----	-----	.006	.15	−.02	+.03
14	do	do	85	30	105	40	20	2	150	16	.001	.025	.006	.15	−.12	−.07
15	Type	do	85	30	105	40	20	2	150	16	.001	.025	.006	.15	−.12	−.07
16	do	do	85	30	105	40	20	2	150	16	.002	.05	.012	.30	−.15	−.10
17	do	do	----	----	105	40	------	------	150	16	-----	-----	.006	.15	−.05	.00

In most experiments the shells were smaller than the molds, and the contraction of the nickel-copper shells was always greater than of the copper alone. With the latter, the contraction was significant only with shells deposited at a relatively low temperature (experiment 5). The absence of a measurable change when the copper was deposited at a high temperature, even at a high-current density, was propably due to the fact that, as previously explained, the wax mold on a type-metal base was slightly larger (about 0.03 per cent) at the elevated temperature. Hence, the small contraction produced by deposition may have just compensated for this tendency to expand. Strictly speaking, the contraction caused by the deposition itself on either the wax or lead molds at the higher temperature was, therefore, about 0.03 per cent greater than that shown in Table 3. Practically, however, the actual changes in dimensions of the shells are significant.

The shrinkage produced in depositing nickel-copper shells was relatively large (from 0.12 to 0.15 per cent) but fairly uniform, regardless of whether a plain or type form was used, or whether the shells varied in thickness by as much as 100 per cent. In the latter case, the contraction was slightly greater, but not sufficiently different to affect the register.

The last column in Table 3 shows that the changes in molding and in depositing tend to compensate each other. Hence, the dimensions of the shells are not much different from those of the patterns. As will be seen, the changes in casting and curving are relatively large. If these operations could be eliminated, there would be little difficulty in obtaining plates of uniform dimensions. This elimination is not practicable in regular electrotyping as now practiced, but it has been accomplished by making the entire printing plate of deposited metal; for example, of iron, at the Bureau of Engraving and Printing,[7] or of copper as is being done for special purposes in a few electrotyping plants.

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[7] C. T. Thomas and W. Blum, Trans. Am. Electrochem. Soc., **57**, p. 59; 1930.

TABLE 4.—*Dimensional changes in casting*

Experiment No.	Pattern	Electrotype metal composition			Shell thickness				Casting temperature		Rate of cooling	Change—	
		Pb	Sn	Sb	Nickel		Copper					In casting	From original[1]
		P. ct.	*P. ct.*	*P. ct.*	*Inch*	*mm*	*Inch*	*mm*	°*F.*	°*C.*		*P. ct.*	*P. ct.*
18	Plain	93	4	3	------	------	0.006	0.15	635	335	Fast	−0.18	−0.15
19	do	93	4	3	0.001	0.025	.006	.15	635	335	do	− .15	− .22
20	do	93	4	3	.001	.025	.006	.15	790	420	do	− .14	− .21
21	do	93	4	3	.001	.025	.006	.15	635	335	Slow	− .16	− .23
22	do	93	4	3	.002	.05	.012	.30	635	335	do	− .09	− .18
23	do	88	9	3	.001	.025	.006	.15	635	335	do	− .11	− .18
24	Type	93	4	3	------	------	.006	.15	635	335	Fast	− .15	− .15
25	do	93	4	3	.001	.025	.006	.15	635	335	do	− .17	− .24
26	do	93	4	3	.001	.025	.006	.15	790	420	do	− .15	− .22
27	do	93	4	3	.001	.025	.006	.15	635	335	Slow	− .16	− .23
28	do	93	4	3	.002	.05	.012	.30	635	335	do	− .14	− .24
29	do	88	9	3	.001	.025	.006	.15	635	335	do	− .16	− .23

3. CASTING

The data in Table 4 show clearly that the casting process always causes shrinkage of the plates. The most reasonable explanation is that the solid electrotype metal has a higher expansivity than the copper shell. Hence, when the cast plate cools, the type metal tends to contract the copper. This effect can not start until the electrotype metal has solidified, as above the melting point of the type metal the latter and the copper are free to expand and contract independently. As the electrotype metal freezes at about 527° F. (275° C.) (see fig. 3) we may assume that the differential contraction of the type metal and copper is significant from about 275° C. to 25° C.; that is, for about 250 centigrade degrees or 450 Fahrenheit degrees. The independent contractions in this range would be about as follows:

$$\text{Copper} = 250 \times 0.000018 = 0.0045 = 0.45 \text{ per cent}$$
$$\text{Type metal} = 250 \times 0.000028 = 0.007 \quad = 0.7 \quad \text{per cent}$$

From these figures we might expect that the cast plate would be about 0.25 per cent shorter than the shell, instead of only about 0.15 per cent as shown in Table 4. The difference is no doubt due to the fact that the copper (or copper-nickel) shell has too high a compressive strength to be fully contracted by the electrotype metal. Hence, the latter must either slip or be stretched beyond its elastic limit during the cooling. The net result is a shortening of the plate by an amount that is less than the difference between the two coefficients.

If the above explanation is correct, the casting temperature should have no effect on the shrinkage, as the latter can not start until the metal solidifies. This prediction is borne out by the data in Table 4. (Compare experiment 18 with 20 and 25 with 26.)

Differences in the rate of cooling produce no marked differences in the dimensions. In the "slow" process, the cast plates were allowed to stand on the pans without any artificial cooling. In the "fast" cooling, cold air was blown against the bottom of the pans. The different rates of cooling are shown by the "cooling curves" in Figure 3. These were made by imbedding "chromel-alumel" thermocouples in the type metal as the latter was poured on the pans, and reading the temperatures at regular time intervals by means of a millivoltmeter. In all cases it was observed that the "break" in the curve; that is, the freezing point, occurred at about 527° F. (275° C.), even with type metals of different compositions. It is recognized that an accurate measurement of the melting or freezing point was not obtained under these conditions, as the metal was not stirred while cooling. The results represent, however, the approximate cooling rates of the type metal under the conditions used.

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[1] These values were obtained by assuming lead molding, copper deposition at 105° F. (40° C.), and nickel deposition at 85° F. (30° C.).

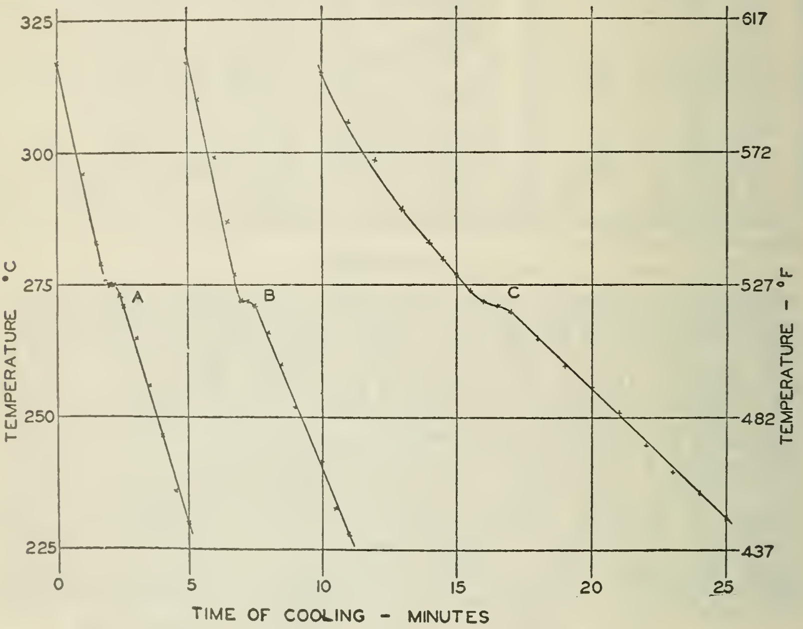

Fig. 3.—*Cooling curves for electrotype metal in the casting pans*

The "break" in each curve represents the freezing or solidification of the metal.
A, 88 per cent lead, 9 per cent tin, and 3 per cent antimony. Cooled rapidly.
B, 93 per cent lead, 4 per cent tin, and 3 per cent antimony. Cooled rapidly.
C, 93 per cent lead, 4 per cent tin, and 3 per cent antimony. Cooled slowly.
(For convenience the initial readings are spaced at 5-minute intervals. To compare *B* or *C* with *A*, 5 minutes should be deducted from the values on *B*, and 10 minutes from those on *C*.)

An increase in the tin content of the type metal produced a somewhat smaller contraction of the plain plates (compare experiment 21 with 23), but no similar difference with the type pattern (compare experiment 27 with 29). The higher tin content presumably reduces slightly the expansivity of the electrotype metal, which would result in a smaller contraction of the cast plate. The larger contraction with the type pattern may be due to the fact that the latter presents a rough surface and, therefore, retards any slippage, and also that the corrugated surface of the shell is more easily contracted than is a plain surface. Any warping of the plates is likely to make their measured dimensions less than those when the plate is plane.

The other factor that caused a variation in the contraction was the thickness of the shell. The smaller contraction of a thick shell (compare experiment 21 with 22) is to be expected since the thicker copper and nickel would offer more resistance to shrinkage. Here again the effect is negligible with the type pattern, probably for the reasons stated above.

In general, it may be concluded that the casting process produces a contraction of about 0.15 per cent, which value is not appreciably affected by differences in the temperature of casting or rate of cooling; but it may be changed slightly, especially on plain plates, by a change in the composition of the type metal or in the shell thickness. As the deposited shells have nearly the same dimensions as the originals, the contraction in casting always results in a cast plate that is smaller than the originals.

4. FINISHING

The cast plates are not likely to have a plane printing surface, as both the deposition and the casting tend to produce distortions. The purpose of the finishing process is to straighten the plate so that the entire printing surface is in one plane. This operation generally tends to cause an increase in the dimensions of the plate. The extent of this stretch depends upon the amount of finishing required and the method used to eliminate defects that may have been present in the original patterns or produced in the electrotyping process. It is therefore difficult to obtain data that represent "average" conditions. The results in Table 5 are simply typical values that show the probable magnitudes of the changes.

TABLE 5.—*Dimensional changes in finishing*

Experiment No.	Pattern	Shell metal	Method of finishing	Change—	
				In finishing	From original [1]
				Per cent	*Per cent*
30	Plain	Copper	Hand hammering	+0.14	−0.01
31	do	Nickel-copper	do	+.09	−.21
32	do	Copper	Cold press	+.03	−.12
33	do	Nickel-copper	do	+.03	−.17
34	do	Copper	Hot press	−.11	−.26
35	do	Nickel-copper	do	−.08	−.28
36	Type	Copper	do	−.09	−.24
37	do	Nickel-copper	do	− 06	−.29
38	do	Copper	Cold press	+.10	−.05
39	do	Nickel-copper	do	+.08	−.15

[1] These values were obtained by assuming lead molding, copper deposition at 105° F. (40° C.), and nickel deposition at 85° F. (30° C.).

In the common practice of hammering the back of the plates at the points that are too low on the printing surface, the amount of stretch is variable. In some cases at least the expansion thereby produced is just sufficient to bring the dimensions back to the original. At best, however, hand finishing is troublesome and expensive, and in recent years many efforts have been made to perform this process mechanically.

Straightening in a press at ordinary temperature also causes expansion, the extent of which depends largely on the pressure applied. This expansion by pressure is similar to but greater than that produced by molding, in which lower pressures are generally used. The results obtained indicate that for similar plates and designs and at a controlled pressure, the expansion is fairly uniform. Type plates expand more readily than plain plates. In all cases the net result is to make the plate dimensions approach the originals.

When the plates are straightened in a press at a temperature of approximately 500° F. (260° C.); that is, just below the melting point of the type metal, there is a tendency to contract. Apparently in this second cooling of the electrotype metal, its high coefficient of expansion (or contraction) causes it to produce additional shrinkage of the copper. Plates straightened by this method are likely to be appreciably shorter than the originals.

Tests not recorded in the tables showed that increasing the thickness of the shells had no appreciable effect upon the changes produced by finishing with any of the above processes.

5. CURVING

If a flat homogeneous plate is bent around a cylindrical mandrel, the outer or convex surface tends to expand from tension, and the inner or concave surface tends to contract from compression. If we assume in the ideal case that the effect of the tension is exactly equal to that of compression, the proportional stretch of the outer surface is equal to the thickness of the plate divided by the outside diameter of curvature. This assumption implies that there is in the middle of the plate a "neutral plane" which neither expands nor contracts.

The plates used in this investigation, had a thickness of 0.183 inch (4.65 mm), and were curved to yield an outside diameter of 12.500 inches (317.5 mm).[8] According to the above formula, the percentage stretch would be

$$\text{Per cent stretch} = \frac{\text{Thickness} \times 100}{\text{Diameter}} = \frac{0.183 \times 100}{12.5} = 1.46 \text{ per cent}$$

Actually the average stretch for all the plates included in Table 6 is 1.42 per cent. This close average agreement is, however, largely a coincidence, as under different conditions the stretch varied from 1.02 to 1.65 per cent, for reasons that will be discussed. Even under specified conditions the results were not as reproducible as those obtained in other operations. Small differences in the tabulated results are, therefore, not significant.

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[8] As these plates were made for use on a cylinder with a diameter of 12.125 inches (308 mm), the desired outside diameter would correspond to a plate thickness of 0.1875 inch (4.76 mm). A smaller plate thickness, in this case 0.183 inch (4.65 mm), is generally used in order to allow for an "under lay" of paper in the "make-ready"; that is, the process of bringing all parts of the printing surface into the position needed to give it the desired "printing value."

TABLE 6.—*Dimensional changes in curving*

Experiment No.	Pattern	Electrotype metal			Shell thickness				Rate of cooling	Hours till curved	Method of curving	Change—	
		Pb	Sn	Sb	Nickel		Copper					In curving	From original[1]
		P. ct.	*P. ct.*	*P. ct.*	*Inch*	*mm*	*Inch*	*mm*				*P. ct.*	*P. ct.*
40	Plain	93	4	3	------	------	0.006	0.15	Slow	24+	Cold	+1.41	+1.29
41	do	93	4	3	0.002	0.05	.012	.30	do	24+	do	+1.02	+ .85
42	do	93	4	3	.001	.025	.006	.15	do	24+	do	+1.30	+1.13
43	do	93	4	3	.001	.025	.006	.15	do	24+	Hot	+1.33	+1.16
44	do	93	4	3	.001	.025	.006	.15	do	2	Cold	+1.29	+1.12
45	do	88	9	3	.001	.025	.006	.15	do	24+	Hot	+1.22	+1.05
46	Type	88	9	3	.001	.025	.006	.15	do	24+	do	+1.58	+1.43
47	do	93	4	3	.002	.05	.012	.30	do	24+	do	+1.41	+1.26
48	do	93	4	3	.002	.05	.012	.30	do	24+	Cold	+1.35	+1.20
49	do	93	4	3	.001	.025	.006	.15	Fast	24+	do	+1.53	+1.38
50	do	93	4	3	.001	.025	.006	.15	do	24+	Hot	+1.65	+1.50
51	do	93	4	3	.001	.025	.006	.15	Slow	24+	Cold	+1.51	+1.36
52	do	93	4	3	.001	.025	.006	.15	do	24+	Hot	+1.60	+1.45
53	do	93	4	3	.001	.025	.006	.15	do	2	Cold	+1.49	+1.34
54	do	93	4	3	------	------	.006	.15	do	24+	do	+1.56	+1.51

[1] These values were obtained from assuming lead molding, copper deposition at 105° F. (40° C.), nickel deposition at 85° F. (30° C.), and cold-press method of finishing.

An electrotype plate is not homogeneous, and the outer shell is much stronger than the electrotype metal that constitutes over 90 per cent of the plate. Hence, the neutral plane as above defined is nearer to the printing surface, and on curving, the plate stretches like a thinner plate; that is, the expansion is less than that calculated as above. This is illustrated by the data in Table 6 for plain plates, for which the average stretch is only 1.26 per cent.

On the other hand, the type pattern represents a surface corrugated in the direction perpendicular to that of curvature. When such plates are bent, the average increase in length is 1.52 per cent; that is, slightly greater than that calculated. In bending a type plate the increase in length of the printing surface is caused not only by stretching the shell, but also by bending the latter where the vertical portions meet the depressed horizontal portions. This is illustrated in Figure 4. The depressions in the face have the same effect as if the diameter of the plate were decreased, while the thickness (as defined by the printing surface) remains constant.

This same effect is observed to an even greater degree if certain areas of the plate are routed out before the plate is curved. Experiments not recorded in the table showed that the stretch of a routed plate is much greater than of an unrouted plate. This difference is due partly to a decrease in the effective diameter as above noted, and also to the reduction in the strength of the shell by removing portions of it. It is therefore preferable to rout the plates after curving. It was found in these tests that this subsequent routing does not change the dimensions of the curved plate. When it is practicable to reduce or eliminate the routing by "building up" the wax mold, the shell is continuous, and the stretch is more nearly uniform than that of a plate routed before curvature.

With either kind of plate, the stretch was decreased by any increase in strength of the shell such as may be produced by using both nickel and copper, by increasing the thickness, or by increasing the strength of the copper; for example, by the use of addition agents. A few tests not recorded in the table showed that plates made from shells deposited in a copper solution that contained no phenolsulphonic acid stretched slightly more than those here recorded. The smallest stretch (1.02 per cent) was obtained with a nickel-copper shell, plain form and of double thickness.

A slight decrease in the stretch of plain plates was caused by increasing the tin content of the electrotype metal (compare experiment 43 with 45), but any such effect with the type pattern was very small (compare experiment 46 with 52). As the addition of tin hardens the type metal, a decreased stretch would be expected.

No appreciable difference was observed in the stretch whether the cast plates were cooled rapidly or slowly (compare experiments 51 with 49, and 52 with 50). Similarly it made no difference whether the plates were curved soon after casting (within about two hours), or after 24 hours or more.

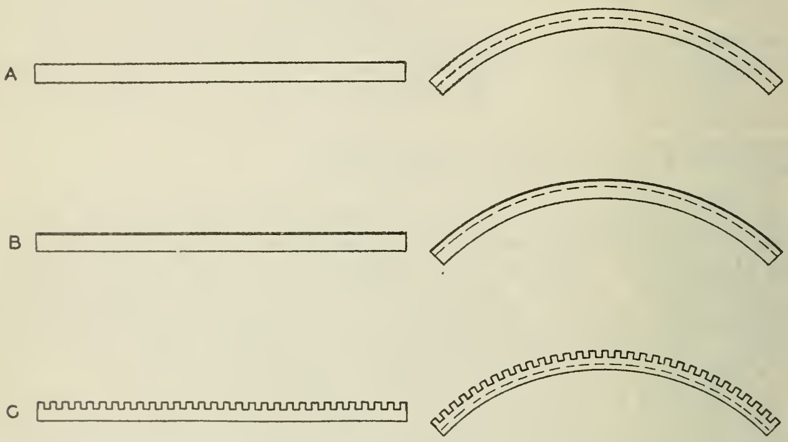

FIGURE 4.—*Diagram showing types of curved plates*

A. A homogeneous plate. When curved the convex surface stretches approximately in accordance with the equation

$$\text{Per cent stretch}=\frac{\text{Plate thickness}\times 100}{\text{Diameter of curvature}}$$

The neutral plane is in the center.

B. A plain electrotype plate, with a shell of copper or nickel, backed-up with electrotype metal. The stretch is less than that calculated in *A*. The neutral plane is closer to the outer surface.

C. An electrotype of a type pattern. This stretches slightly more than that calculated in *A*. The neutral plane is closer to the inner surface.

The cold curving was done at room temperature with the ordinary 3-roll bender. In this method the plates are rolled to fit the mandrel, a hemicylinder which is known in electrotyping as the "turtle." In hot curving the plate is heated to about 480° F. (249° C.) and is then bent directly to fit the appropriate cylinder. In general, the hot curving produced a slightly greater stretch than cold curving. The difference was not significant with the plain plates (compare experiment 42 with 43), but was appreciable with the type plates (compare experiments 51 with 52, and 49 with 50). The greater stretch in hot curving is probably caused by the fact that at the higher temperature the electrotype metal softens relatively more than does the shell. The results with hot curving were somewhat more uniform than with cold, and the hot-curved plates retained their curvature better than did the cold-curved plates.

At best it is difficult to produce curved plates of equal dimensions. When a given method of curving is used, the results are fairly reproducible if the shells are of the same thickness, strength, and type of pattern and if the type metal is of uniform composition. This conclusion agrees with the common experience that it is much easier to make several plates of a series with accurate register if they are produced simultaneously than at different times. For example, when a single plate is required to replace a spoiled one of a set, it is often difficult to make it register, because then the conditions may not be the same as when the first plates were made.

As previously noted, it is occasionally desirable to produce electrotype plates that have exactly the same dimensions as the originals. The results described above show that it may be possible, though difficult, to produce flat plates that meet this requirement. Inspection of the data in Table 5 shows that the stretch produced by cold finishing tends to compensate for the contraction in casting. In special cases the finishing operation may be deliberately extended in order to restore the original dimensions.

In the ordinary methods of curving, however, the stretch is usually 1 per cent or more. If uniform, this stretch is not objectionable for regular printing. For "dimensional" printing, however, such plates are useless. One way to overcome this difficulty is to make the pattern plates shorter in the direction in which they are to be curved. This involves a preliminary measurement of the stretch. In another ingeneous method, commonly known as the "nonstretch" process, electrotype metal is poured upon the face of a finished flat electrotype which has been treated with chalk or graphite to prevent the metal from sticking permanently. As a first approximation it might be assumed that when such a plate is cast so as to have the printing face practically in the middle, and is then curved by the usual methods, the printing surface would become the "neutral plane"; that is, it would neither stretch nor contract during the curving.

In order to determine the effectiveness of this procedure a few experiments were made with the same patterns used above. The results showed clearly that if the printing surface is in the center of the plate there is still an appreciable stretch. This can be reduced by making the added type metal layer thicker than the layer on the under side of the shell. For example it was found that if the plate (including the shell) had a thickness of 0.094 inch (2.35 mm) and type metal was cast on the face to a thickness of 0.166 inch (4.2 mm), thus making the total thickness 0.260 inch (6.6 mm) and the plate was subsequently curved on the 3-roll bender, the stretch of either a plain or type plate was only about 0.15 per cent. When, however, the thickness of the added type metal was increased to make the total thickness 0.354 inch (9.0 mm) and the plate was then curved, there was an actual contraction in length of the printing surface.

To eliminate the stretch the shell must evidently be closer to the inside than to the outside surface. It is necessary to determine by experiment what thickness of type metal must be applied to the surface to reduce the stretch to approximately zero. When this is once determined for a plate and shell of specified thickness and curvature, fairly uniform results can be obtained. It is readily possible thereby to reduce the stretch to about 0.2 per cent, which tends to counteract the shrinkage caused in casting. (This compensation occurs only in the direction of curving, and not in the other direction.) At best it is very difficult to produce finished curved plates that reproduce the originals within about 0.2 per cent in both directions.

V. SUMMARY

The different operations in the electrotyping process produce the following changes in dimension and must be controlled accordingly to produce plates with uniform dimensions.

1. MOLDING

Wax molds are almost exactly the same size as the originals. Lead molds are slightly larger (about 0.05 per cent) than the originals. No special precautions are required to produce uniform plates by either method of molding, but plates made by the two methods are not likely to match each other exactly.

2. DEPOSITING

When copper shells are deposited from cold solutions there is a slight contraction (about 0.05 per cent). The use of warm solutions at a high-current density produces the desired hardness with no appreciable change in dimensions. Nickel-copper shells always contract by about 0.15 per cent. This value is not affected by increasing the thickness of copper and nickel. Such a change in thickness does, however, materially affect the stretch in curving. It is therefore important to keep the conditions for nickel and copper deposition constant, and to produce shells of uniform thickness and strength.

3. CASTING

Casting always causes a shrinkage of about 0.15 per cent, which is not much affected by the temperature of casting or the rate of cooling. Any large change in composition of the electrotype metal will affect the shrinkage. Shrinkage is decreased by increasing the thickness of the shells.

4. FINISHING

Hand finishing always stretches the plates, by amounts that vary with the extent of the finishing operation. Straightening under pressure at ordinary temperature also stretches the plate, but more uniformly than does hand finishing. Straightening in a hot press causes a contraction of about 0.10 per cent.

5. CURVING

The stretch of plain plates in curving is usually less than that calculated from the formula for a homogeneous plate; and a type form stretches more than calculated. Hot curving may produce a slightly greater stretch than cold curving. With a given method, most uniform results are obtained when the shells are of the same thickness and strength and have the same type of pattern, and when the electrotype metal is of the same composition. The temperature of casting and rate of cooling of the electrotype metal have little, if any, effect on the stretch in curving.

In curving by the "nonstretch" method, it is possible by adjusting the thickness of metal cast upon the face of the plate to reduce the stretch to approximately zero. If too much metal is applied, shrinkage may be produced in curving.

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